Distillation Absorption 2010
A.B. de Haan, H. Kooijman and A. Górak (Editors)

TRAY STABILITY AT LOW VAPOR LOAD

Daniel R. Summers[1], Lothar Spiegel[2] and Ekaterina Kolesnikov[3]
[1] Sulzer Chemtech USA, Inc. Tulsa, Oklahoma USA, Email: dan.summers@sulzer.com
[2] Sulzer Chemtech AG, Winterthur, Switzerland, Email: lothar.spiegel@sulzer.com
[3] Sulzer Chemtech AG, Winterthur, Switzerland, Email: katja.kolesnikov@sulzer.com

Abstract
Tower operation at low vapor rates is typically limited by the onset of weeping which can severely hurt tray performance. Many authors have attempted to study the onset of weeping on distillation trays as well as to determine the amount of weeping present. This paper will address this issue from a different perspective which is the uniformity of vapor passage through the tray deck at low vapor loads. It will be shown that there exists a relationship between the onset of weeping, tray performance, dry tray pressure drop and hydrostatic head of liquid on the tray. In addition, this relationship will be addressed with regards to single pass as well as multi-pass trays.

Keywords: turndown, weeping, stability, tray

1. Introduction

Distillation trays need to maintain as uniform a vapor distribution as possible to maintain the highest potential efficiency. A uniform vapor distribution is a key indication that froth gradient has been minimized and that the potential for vapor cross-flow channeling[1] is eliminated. To ensure a uniform vapor distribution, the highest possible dry tray pressure drop should be employed at design or enabled during operation. However, too high of a dry tray pressure drop will lead to premature flooding by spray fluidization[2], pressure drop in excess of design requirements, downcomer backup due to high overall pressure drop and/or deck openings that are too widely spaced to enable good vapor/liquid contacting on the tray deck. Therefore, it is more practical to employ a dry tray pressure drop that is just sufficient to prevent significant weeping and maintain good tray performance at the design minimum vapor load of the tower.

2. Discussion

Several people have attempted to define a minimum value to the dry tray pressure drop for maintenance of good tray hydraulic performance. Addressing this issue with dry tray pressure drop alone can lead to poorly performing trays when the outlet weir height is very different than typical values of 40 to 50 mm. It is the purpose of this paper to propose that a relationship exists between the dry tray pressure drop and hydrostatic head on a distillation tray such that operation below a particular minimum value will result in poor tray performance. This relationship is proposed here to be called a <u>stability factor</u> and should be added to a tray designers list of key hydraulic parameters that need to be examined when concerned with the minimum operating loads of a distillation tower.

The Froude number is well known in the distillation industry as a dimensionless term that represents the ratio of an upwards inertial force against a downwards gravitational force. In tray design, this is listed typically as:

$$Fr_h = V_h\,(\rho_v)^{0.5}/(g\,H_{CL}\,\Delta\rho)^{0.5} \qquad (1)$$

Since dry tray pressure drop for sieve holes and fixed opening valves is equal to;

$$\Delta P_{DRY} = C_P\,V_h^{2}\,\rho_v \qquad (2)$$

then the Froude number is proportional to the square root of the dry tray pressure drop divided by the hydrostatic head of liquid;

$$Fr_h \sim (\Delta P_{DRY} / H_{CL})^{0.5} \qquad (3)$$

It is proposed that a measure of tray stability can be found with this term and can be defined as a tray's stability factor with the Greek symbol η;

$$\eta = (\Delta P_{DRY} / H_{CL})^{0.5} \qquad (4)$$

Lockett and Banik[3] have successfully examined sieve tray weeping using the Froude number. They plotted weep flux, which is weep rate (m^3/s) divided by tray hole area, against the inverse Froude number. For example, a plot of the weep flux for the Sulzer MMVG™ tray[4] against the inverse Froude number, as shown in Figure 1, shows that at zero weep flux, the Froude number has a finite value of 1/1.21 or 0.83. This data was taken from Sulzer's 4 foot (1219 mm) air-isopar and air-water simulator in Tulsa. One could interpret the results of such a plot for MMVG trays, such that the Froude number needs to remain above 0.83 to ensure stable operation.

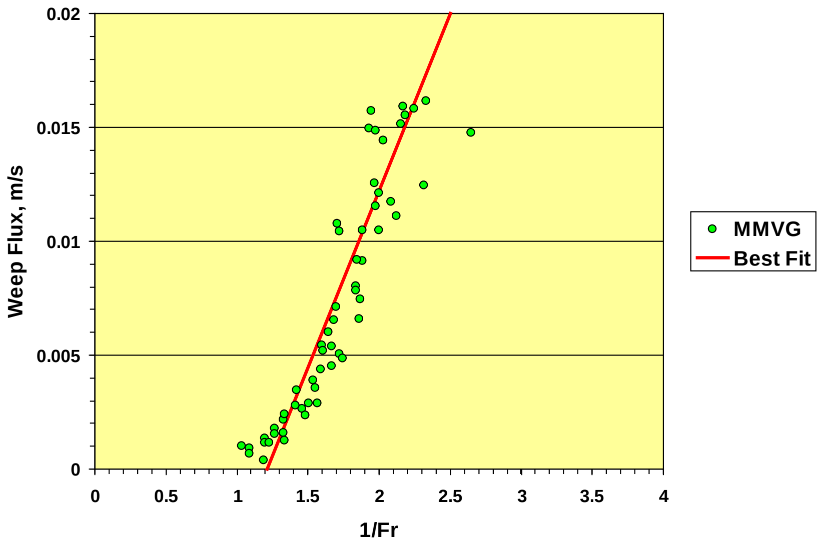

Figure 1. Weep Flux vs. Inverse Froude Number for Sulzer MMVG Trays

Certainly at zero weeping a distillation tray is fully stable. In practical terms however, based on operational and laboratory experience, distillation trays can operate quite efficiently and stably with small amounts of uniform weeping through the tray decks[5,6]. Based on the authors' experience and literature interpretation of weeping effects on tray efficiency, we have chosen to assume that uniform weeping of less than 30% of the tray's liquid load will result in small adverse effects on tray performance. Therefore, if one plots % weeping for the MMVG tray against the stability factor as defined in equation 4, they will generate Figure 2. Here it can be clearly seen that any value of stability factor above 0.6 has less than 30% weeping.

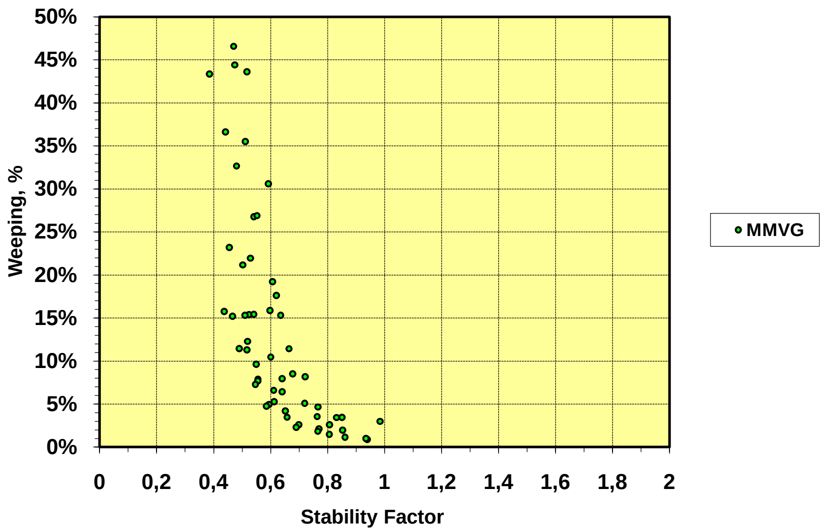

Figure 2. % Weeping vs. Stability Factor for Sulzer MMVG™ Trays

If this same study is made for other commercially available tray types[7], a similar conclusion can be drawn. As shown in Figures 3-6, except for only 4 data points out of a total of 688, a stability factor above 0.6 shows no significant weeping from all the various type tray decks. One interesting observation from this data reduction is that this conclusion appears to also apply to movable opening devices such as the Sulzer BDH™ tray as shown in Figure 5. There does however appear to be more scatter in this Figure 5's data, which is understandable since dry tray pressure drop for movable valves is much more complex.

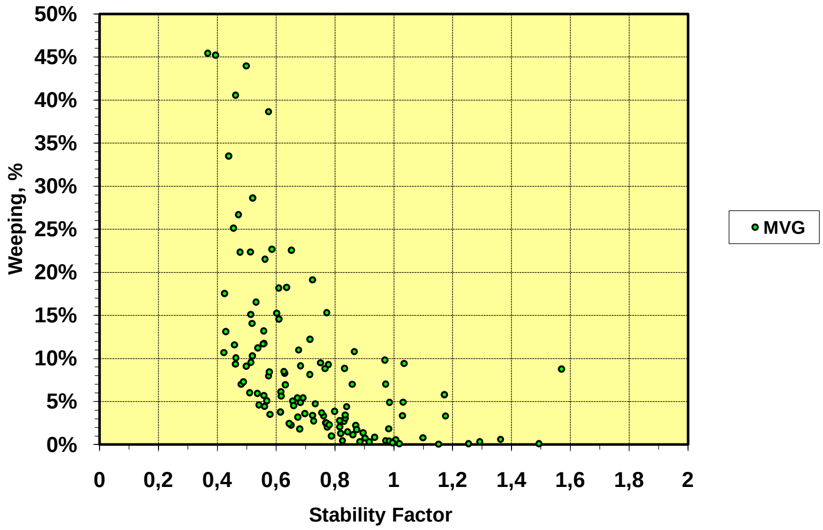

Figure 3. % Weeping vs. Stability Factor for Sulzer MVG™ Trays

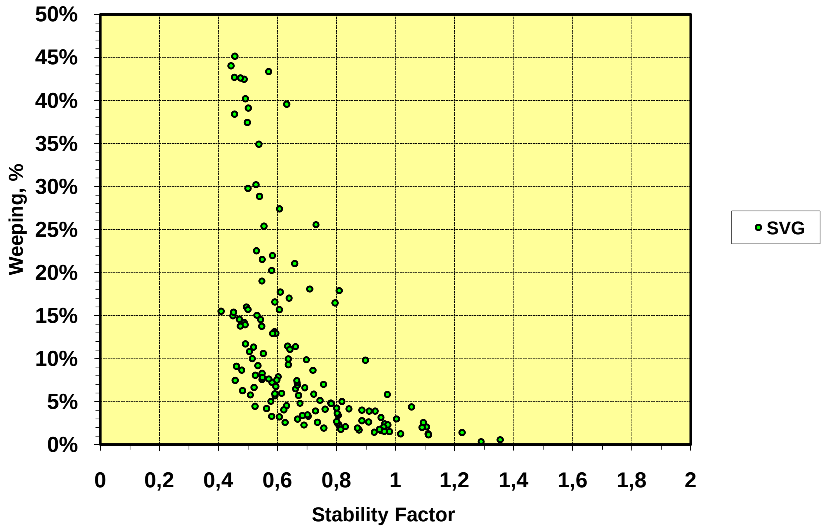

Figure 4. % Weeping vs. Stability Factor for Sulzer SVG™ Trays

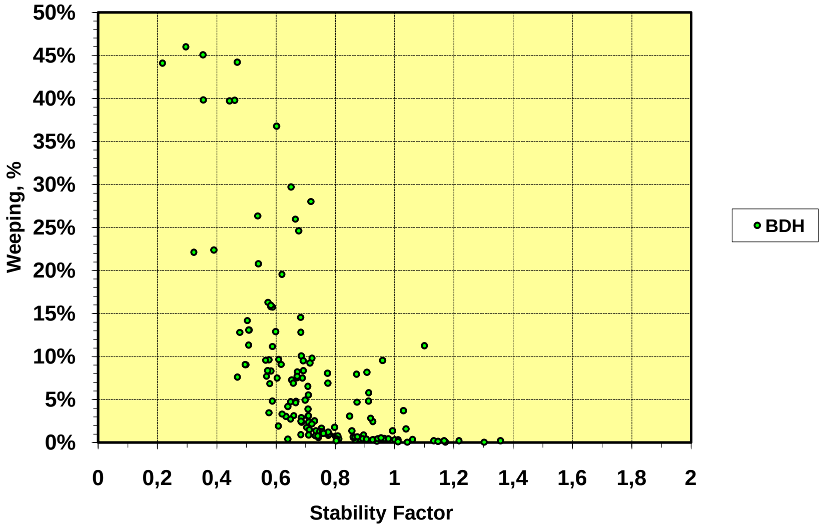

Figure 5. % Weeping vs. Stability Factor for Sulzer BDH™ Trays

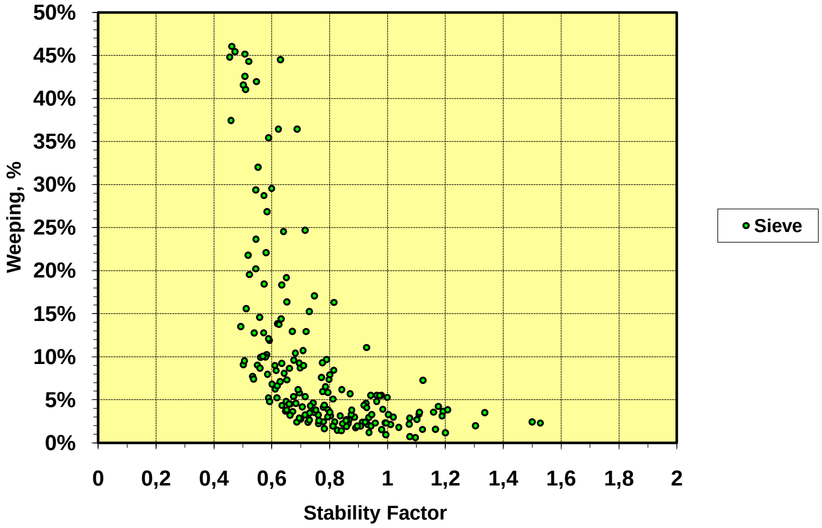

Figure 6. % Weeping vs. Stability Factor for ½" hole diameter Sieve Trays

For all the above data, the dry tray pressure drop is defined as it was originally presented in references 8 and 9. The dry tray pressure drop uses the vapor rate and vapor density from the given laboratory data[4] as well as the open area of the specific test tray. The hydrostatic head (or clear liquid head) was obtained in a simple manner by taking the total tray pressure drop data and subtracting the calculated dry tray pressure drop, not too dissimilar to the procedure by Lockett[3] .

Multipass Tray Instability Discussion

For Multipass there is additional opportunities for the trays to become unstable, totally unrelated to weeping. Multi-pass trays have shown, in some cases, that they can allow the vapor to travel upwards through the tower without flowing through all of the tray's passes. Multi-pass trays, including 2-pass, have natural barriers to vapor flow, which are commonly referred to as downcomers, that prevent vapor from reaching all of the tray passes. It has been one of the authors' experiences to witness this phenomenon in a tower where the entire vapor passed upwards through a single side of a 2-pass trayed column. This was discerned by observing a frost pattern on the outside of this uninsulated tower early in the morning before the sun came up. There was a clear indication that the cold liquid was isolated to only one side of the tower. This problem was remedied by properly adjusting the tray's pressure balance, through a severe reduction in the tray open area. The author employed the methodology as outlined below to determine the open area of this tower. To avoid vapor from completely ignoring one of a tray's flow passes on a multi-pass tray, the pressure drop through the inactive side should not be greater than the fully active side(s);

$$\Delta P_{ACTIVE} > \Delta P_{INACTIVE} \qquad (5)$$

The theory is that if the pressure drop on the active side is higher than the inactive side, then the vapor will always want to pass through the inactive side, thus keeping the tray stable. The active tray panel for 2-pass trays for example will experience twice the normal vapor flow. Assuming that the liquid flow continues to distribute itself evenly among all the tray passes, then a pressure balance relationship can be established;

$$\Delta P'_{DRY} + H_{CL} > \Delta P_{INACTIVE} \qquad (6)$$

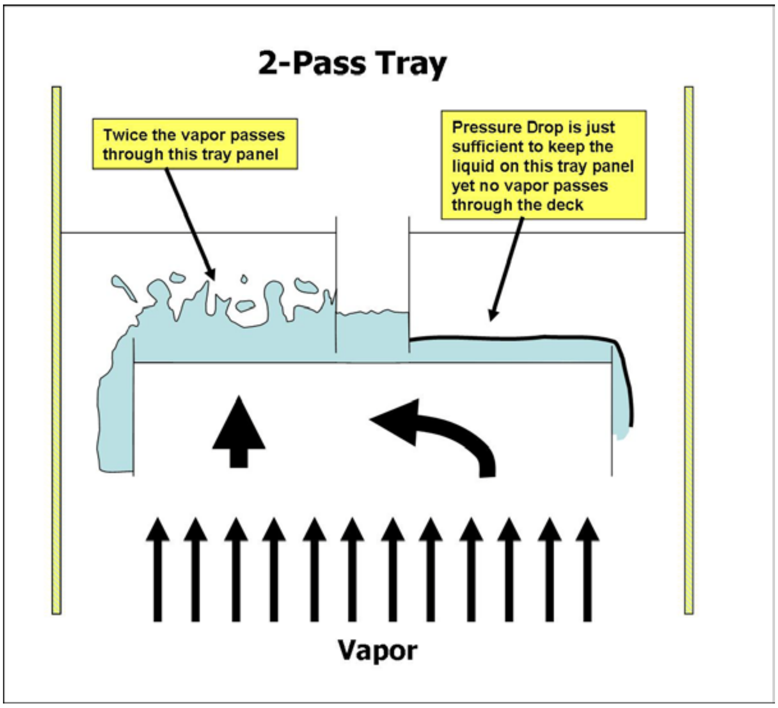

Figure 7. Pressure Balance Sketch

The highest potential pressure drop on the inactive side will basically be the height of the outlet weir plus the crest over that weir if one assumes no weeping. This of course is not realistic, but this assumption is made so that the calculation can be as conservative as possible with respect to the pressure balance.

$$\Delta P_{INACTIVE} = H_C + H_{OW} \qquad (7)$$

The crest over the weir for the inactive tray panel can be represented by a modified Francis Weir Formula[10] for the non-aerated liquid which can be rearranged to be;

$$H_C = 0.6665\ (WL)^{2/3} \qquad (8)$$

The resulting pressure balance equation, as depicted in Figure 7, is then;

$$\Delta P'_{DRY} + H_{CL} > H_C + H_{OW} \qquad (9)$$

Using an equal bubbling area design for all tray passes, when the tray vapor does not pass through one of the tray passes, one can assume that the vapor will distribute to the remaining tray passes equally resulting in the following increase in dry tray pressure drop;

$$\Delta P'_{DRY} = \Delta P_{DRY} [n/(n-1)]^2 \qquad (10)$$

For 2-pass trays $[n/(n-1)]^2$ is equal to 4 because twice the vapor flowing through the remaining panel will increase the dry tray pressure drop by the square of the vapor flow. For 4-pass trays, the increase is only 1.78 times the normal dry tray pressure drop. Therefore, for multi-pass trays to remain stable they need to keep the stability factor above 0.6 and the dry tray pressure drop above this value;

$$\Delta P_{DRY} = (H_C + H_{OW} - H_{CL}) / [n/(n-1)]^2 \qquad (11)$$

To ensure the most conservative value to the minimum allowable dry tray pressure drop in equation 11 for multi-pass trays, the crest height should use the tray path with the shortest weir length. This is typically the tray panel with the side downcomer associated with it. The hydrostatic head in this equation is calculated for the aerated liquid from Colwell[11]. This equation has been checked against fully balanced multi-pass trays, and found to typically require a higher dry tray pressure drop than what is necessary to satisfy the above mentioned stability factor for any particular tray panel. It has been found that this equation will not be practical for outlet weir heights less than 0.5 inches. The use of this equation 11 assumes that good multi-pass tray design practice is employed such as for 4-pass trays[12] and all outlet weir heights are the same on all tray passes.

3. Conclusions

In conclusion, an alternative method for looking at tray operation at low vapor loads is presented. An equation for tray stability is provided for single pass trays and individual tray panels of multi-pass trays. In addition, an additional equation is suggested for multi-pass trays to ensure that all tray passes will have vapor passing through them.

Nomenclature

C_P	Orifice Coefficient	V_h	Vapor Hole Velocity, m/s
Fr_h	Froude Number of the tray openings	ΔP_{DRY}	Dry Tray Pressure Drop, m hot liquid
G	Gravitational acceleration, 9.80664 m/s^2	$\Delta P'_{DRY}$	Dry Tray Drop at Higher Vapor Load, m hot liquid
H_C	Crest Height, m	ΔP_{ACTIVE}	Tray Pressure Drop on active Panels
H_{CL}	Hydrostatic Head of Liquid, m	$\Delta P_{INACTIVE}$	Tray Pressure Drop on inactive Panels
H_{OW}	Height of outlet weir, m	$\Delta\rho$	Liquid and Vapor Density Difference, kg/m^3
N	Number of Tray Passes	ρ_v	Vapor Density, kg/m^3
WL	Weir Loading, m^2/s	η	Stability Factor

References

1. Kister, H.Z., Larson, K.F., and Madsen, P.E., *CEP* (November 1992) 86-93
2. Summers, D.R., and Sloley, A., *Hydrocarbon Processing*, (January 2007) 67-78
3. Lockett, M.J., Banik, S., *Ind. Eng. Chem. Process Des. Dev.*, 25 (1986) 561-569
4. Sulzer Chemtech Laboratory Data 1993-1998 – Proprietary Information
5. Colwell, C.J. and O'Bara, J.T., *Estimate Sieve Tray Efficiency in the Weeping Region*, AIChE Spring Meeting Paper 27a, (April 1989)
6. Billingham, J.F., Banik, S., and Lockett, M.J., *The Effect of Inlet Weeping on Distillation Tray Efficiency*, AIChE Annual Meeting Paper 134e, (November 1994)
7. Nutter Engineering Data Books – Proprietary Laboratory Data
8. Summers, D.R. and van Sinderen, A., *Distillation 2001, Topical Conference Proceedings, AIChE* (April 2001)
9. Summers, D.R., *Chemical Engineering*, 6 (2009) 36-39
10. Francis, J.B., *Lowell Hydraulic Experiments*, Cambridge: Allen & Farnham Printers (1855)
11. Colwell, C.J., *Ind. Eng. Process Design and Development*, 20 (1981) 298-307
12. Summers, D.R., *Distillation 2009 Topical Proceedings, AIChE* (April 2009)